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‿RTRAG ÜBER DIE INTERNATIO‿ ‿E ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS

PCT

INTERNATIONALER RECHERCHENBERICHT

(Artikel 18 sowie Regeln 43 und 44 PCT)

Aktenzeichen des Anmelders oder Anwalts R. 36024 Sf/Me	**WEITERES VORGEHEN**	siehe Mitteilung über die Übermittlung des internationalen Recherchenberichts (Formblatt PCT/ISA/220) sowie, soweit zutreffend, nachstehender Punkt 5
Internationales Aktenzeichen PCT/DE 00/01929	Internationales Anmeldedatum *(Tag/Monat/Jahr)* 19/06/2000	(Frühestes) Prioritätsdatum *(Tag/Monat/Jahr)* 19/06/1999
Anmelder ROBERT BOSCH GMBH		

Dieser internationale Recherchenbericht wurde von der Internationalen Recherchenbehörde erstellt und wird dem Anmelder gemäß Artikel 18 übermittelt. Eine Kopie wird dem Internationalen Büro übermittelt.

Dieser internationale Recherchenbericht umfaßt insgesamt 2 Blätter.

[X] Darüber hinaus liegt ihm jeweils eine Kopie der in diesem Bericht genannten Unterlagen zum Stand der Technik bei.

1. **Grundlage des Berichts**
   a. Hinsichtlich der **Sprache** ist die internationale Recherche auf der Grundlage der internationalen Anmeldung in der Sprache durchgeführt worden, in der sie eingereicht wurde, sofern unter diesem Punkt nichts anderes angegeben ist.

   [ ] Die internationale Recherche ist auf der Grundlage einer bei der Behörde eingereichten Übersetzung der internationalen Anmeldung (Regel 23.1 b)) durchgeführt worden.

   b. Hinsichtlich der in der internationalen Anmeldung offenbarten **Nucleotid- und/oder Aminosäuresequenz** ist die internationale Recherche auf der Grundlage des Sequenzprotokolls durchgeführt worden, das

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2. [ ] **Bestimmte Ansprüche haben sich als nicht recherchierbar erwiesen** (siehe Feld I).
3. [ ] **Mangelnde Einheitlichkeit der Erfindung** (siehe Feld II).

4. Hinsichtlich der **Bezeichnung der Erfindung**

   [X] wird der vom Anmelder eingereichte Wortlaut genehmigt.
   [ ] wurde der Wortlaut von der Behörde wie folgt festgesetzt:

5. Hinsichtlich der **Zusammenfassung**

   [X] wird der vom Anmelder eingereichte Wortlaut genehmigt.
   [ ] wurde der Wortlaut nach Regel 38.2b) in der in Feld III angegebenen Fassung von der Behörde festgesetzt. Der Anmelder kann der Behörde innerhalb eines Monats nach dem Datum der Absendung dieses internationalen Recherchenberichts eine Stellungnahme vorlegen.

6. Folgende Abbildung der **Zeichnungen** ist mit der Zusammenfassung zu veröffentlichen: Abb. Nr. 4

   [X] wie vom Anmelder vorgeschlagen [ ] keine der Abb.
   [ ] weil der Anmelder selbst keine Abbildung vorgeschlagen hat.
   [ ] weil diese Abbildung die Erfindung besser kennzeichnet.

INTERNATIONALER RECHERCHENBERICHT

Internationales Aktenzeichen
PCT/DE 00/01929

A. KLASSIFIZIERUNG DES ANMELDUNGSGEGENSTANDES
IPK 7 H01L41/083

Nach der Internationalen Patentklassifikation (IPK) oder nach der nationalen Klassifikation und der IPK

B. RECHERCHIERTE GEBIETE

Recherchierter Mindestprüfstoff (Klassifikationssystem und Klassifikationssymbole)
IPK 7 H01L

Recherchierte aber nicht zum Mindestprüfstoff gehörende Veröffentlichungen, soweit diese unter die recherchierten Gebiete fallen

Während der internationalen Recherche konsultierte elektronische Datenbank (Name der Datenbank und evtl. verwendete Suchbegriffe)

EPO-Internal, PAJ

C. ALS WESENTLICH ANGESEHENE UNTERLAGEN

Kategorie°	Bezeichnung der Veröffentlichung, soweit erforderlich unter Angabe der in Betracht kommenden Teile	Betr. Anspruch Nr.
A	US 5 266 862 A (OHYA KAZUMASA) 30. November 1993 (1993-11-30) Spalte 2, Zeile 3-21; Abbildung 3	1
A	EP 0 479 328 A (NIPPON ELECTRIC CO) 8. April 1992 (1992-04-08) Zusammenfassung; Abbildung 8	1

☐ Weitere Veröffentlichungen sind der Fortsetzung von Feld C zu entnehmen

☒ Siehe Anhang Patentfamilie

° Besondere Kategorien von angegebenen Veröffentlichungen :

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"E" älteres Dokument, das jedoch erst am oder nach dem internationalen Anmeldedatum veröffentlicht worden ist

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"X" Veröffentlichung von besonderer Bedeutung; die beanspruchte Erfindung kann allein aufgrund dieser Veröffentlichung nicht als neu oder auf erfinderischer Tätigkeit beruhend betrachtet werden

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"&" Veröffentlichung, die Mitglied derselben Patentfamilie ist

Datum des Abschlusses der internationalen Recherche	Absendedatum des internationalen Recherchenberichts
30. Oktober 2000	07/11/2000

Name und Postanschrift der Internationalen Recherchenbehörde	Bevollmächtigter Bediensteter
Europäisches Patentamt, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Pelsers, L

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/DE 00/01929

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5266862	A	30-11-1993	JP	4159785	A	02-06-1992
EP 0479328	A	08-04-1992	DE	69109990	D	29-06-1995
			DE	69109990	T	12-10-1995
			JP	4214686	A	05-08-1992
			US	5237239	A	17-08-1993

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(54) Piezoelectric actuator.

(57) In a piezoelectric actuator of the type which has a plurality of grooves on the outer side surface of the actuator body, mechanical reliability of the actuator is enhanced by providing grooves also in the respective layers of a material exhibiting electrostrictive effect located over and below the top and the bottom ends of the actuator. Moreover, a further improvement of mechanical strength can be attained by providing additional grooves onto the outer most grooves.

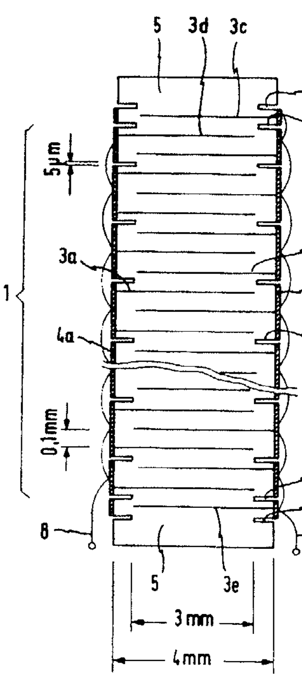


FIG. 8

EP 0 479 328 A2

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a piezoelectric actuator, and more particularly, to a slit type piezoelectric actuator.

Description of Related Art

A piezoelectric actuator is a transducer which converts electric energy to mechanical energy by using the electrostrictive effect of a piezoelectric element.

More specifically, an electrostrictive effect element utilizes the strain generated in the piezoelectric element which exhibits a large electrostrictive effect, such as a lead magnesium niobate-lead titanate ceramic and a lead zirconate titanate ceramic, when an electrode made of a metal or the like is formed on each of two facing surfaces of the piezoelectric element, and a drive voltage is applied between the electrodes.

In the above-mentioned electrostrictive effect, the strain that is generated in the direction parallel to the applied electric field (longitudinal electrostrictive effect) is ordinarily about twice as large as the strain generated in the direction perpendicular to the electric field (lateral electrostrictive effect), so that it is advantageous to utilize the former, and the conversion efficiency from the electrical energy to the mechanical energy is also high.

In an piezoelectric actuator which utilizes the longitudinal electrostrictive effect (referred to as an actuator hereinafter), the amount of displacement per unit length of the actuator is substantially proportional to the intensity of the applied electric field.

Namely, in order to obtain a large amount of displacement it is necessary either to apply a high voltage between the opposing electrodes or to reduce the distance between the facing electrodes.

However, there is required a large-sized and an expensive power unit in order to apply a high voltage, and hazard in handling is also increased, so that it is more desirable to reduce the distance between the facing electrodes.

Heretofore, there is proposed a piezoelectric actuator having the laminated ceramic capacitor type structure to realize the actuator with smaller distance between the facing electrodes.

The structure of the actuator with the above-mentioned type is shown in FIG. 1A and FIG. 1B.

FIG. 1A is a cross-sectional view of the actuator taken in a plane parallel to the lamination direction of the element. In addition, FIG. 1B is a projected view of the actuator in the lamination direction thereof.

As shown in FIG. 1A, this actuator consists of a ceramic part where internal electrodes are provided in its interior with a specified spacing, and a ceramic part where no internal electrode is involved.

The ceramic part which has the internal electrodes in the interior is ordinarily called an active layer 1, and it is the part which contributes to the operation as an element by generating the longitudinal electrostrictive effect in the ceramic when a voltage is applied between the internal electrodes.

In the active layer 1, internal electrodes 3a and 3b are formed with a specified spacing in the interior of ceramic 2, alternately connected for every other layer to external electrodes 4a and 4b that are provided on the side face of the actuator, and the adjacent internal electrodes are mutually forming facing electrodes with a ceramic layer in between.

The distance between the internal electrodes can be made to have a minimum value of about 10 μm by means of the ordinary laminated ceramic capacitor technology.

On the other hand, the part which does not have in its interior the internal electrodes is ordinarily called an inactive layer 5, and it is the part which does not contribute to the operation of the actuator without showing the electrostrictive effect because of the absence of the internal electrodes for applying electric field therebetween. However, this part is necessary to prevent the fluctuation in the components of ceramic 2 of the active layer 1 at the time of high temperature heat treatment during the manufacturing process that will be described later.

By giving the above-mentioned laminated ceramic capacitor structure to the element it is possible to reduce the distance between the internal electrodes of the active layer 1. Therefore, it becomes possible to apply a high electric field to the electrostrictive material even with a low voltage, thereby realizing an element utilizing the longitudinal electrostrictive effect that can be operated at low voltages.

Now, in an actuator with the aforementioned structure the area where the internal electrodes overlap (the portion of the innermost rectangle in FIG. 1B) is small compared with the cross-sectional area of the actuator.

Because of this, when a large strain is generated in the part where the internal electrodes overlap by the application of a voltage to the actuator, there occurs a strong stress concentration in the boundary portion 6 between the part where the internal electrodes overlap and the part where they do not, and there may arise cases in which the actuator is mechanically broken if the applied voltage is high enough.

In order to improve such a defect of the con-

ventional actuator, an actuator is proposed in which grooves (referred to as slits hereinafter) parallel to the internal electrodes are provided on the side face of the laminated ceramic capacitor type piezoelectric actuator.

The actuator with this structure is disclosed in Japanese Patent Laid Open No. 58-196077, and its structure is shown in FIG. 2A and FIG. 2B. An actuator of this structure will be called a slit type actuator hereinafter.

FIG. 2A shows a sectional view in a plane parallel to the lamination direction of the slit type actuator, and FIG. 2B shows the side face of the slit type actuator where external electrodes are not formed.

In this slit type actuator, it is possible to prevent mechanical breakdown of the slit type actuator by dispersing and relaxing the concentration of stress at the time of generation of a displacement in the slit type actuator, by providing a plurality of slits that encircle the side face of the actuator in the parts where no overlap of the internal electrodes exists and hence no strain arises (namely, the portion of the ceramic between the external electrodes 4a and 4b, and the internal electrodes 3b and 3a).

As a result, it is possible to obtain a larger displacement since a voltage higher than for the conventional actuator becomes applicable.

Next, the manufacturing process of the slit type actuator will be described.

First, using the powder of a material that exhibits the electrostrictive effect, such as a lead magnesium niobate-lead titanate ceramic or a lead zirconate titanate ceramic, as the starting material, an organic solvent, a binder, and a plasticizer are added, and a slurry is prepared by stirring and mixing these ingredients.

Next, a ceramic green sheet is prepared from the slurry by doctor blade method or the like.

After drying the green sheet, a paste for internal electrodes having the powder of a silver-palladium alloy as the principal ingredient and a paste for slit forming material having carbon as the principal ingredient are printed over the green sheet by screen printing or the like.

Next, a ceramic laminated body is obtained by integration through stacking and thermocompression bonding.

By treating the ceramic laminated body at 600°C in the air, the binder and the slit forming material are thermally decomposed and dispersed, and there are formed vacancies for the slits.

Subsequently, a ceramic sintered body having in its interior the vacancies for the slits is obtained by calcining the ceramic laminated body at a high temperature of about 1100°C. Then, the sintered body is cut, and after firing a silver paste for external electrodes on the two side faces where the internal electrodes are exposed, lead wires 8 for applying external voltage are connected, completing the slit type actuator.

It is to be noted that in order to take out the displacement of the actuator to the outside in the actual use of the actuator, it is general to bond the top and the bottom end faces of the actuator to metallic jigs 9 using an adhesive 10 or the like to transfer the displacement in the actuator to the metallic jig 9, as shown in FIG. 3.

The prior art slit type actuator sometimes generates the following inconvenience in the course of its manufacturing process.

FIG. 4 shows the state of affairs in the midst of the process for manufacturing a conventional slit type actuator, illustrating a sectional view of lamination of green sheets 13 with the patterns for the internal electrode paste 11 and for the slit forming material 12 being printed. It should be noted that FIG. 4 is drawn with the inactive layer part omitted.

In FIG. 4, the portion of the green sheet indicated as A has no internal electrodes printed, and there are laminated green sheets on which is printed the pattern for the slit forming member 12 alone on every fifth layer.

In contrast, the portion of the figure indicated as B, the pattern for the internal electrode paste alone is printed, and a large number of these layers are laminated.

In the figure, the alternate long and short dash line drawn in the portion where the slit forming materials are laminated (the portion indicated as A) shows the cutting position for segmenting the slit type actuator after sintering the ceramic laminated body.

FIG. 5 is a sectional view of the ceramic sintered body obtained by thermocompression bonding and calcining the ceramic laminated body. In addition to the integration of the whole system, the slit forming material is thermally decomposed and dispersed to form the vacancies 14 for the slits.

In FIG. 5, in the portion indicated as A, the number of layers with printed pattern is small so that the degree of application of the pressure at the time of the thermocompression bonding is weaker compared with the case for the part indicated as B.

Because of this, the amount of contraction at the time of sintering is greater for the portion A than for the portion B, generating a non-uniform contraction as a whole and making the generation of cracks in the portion A easier.

When such cracks 15 are generated, the mechanical strength of the slit type actuator segmented from the ceramic sintered body is reduced so that the element tends to be destroyed when a bending force is applied.

Furthermore, when large and deep cracks that

reach even to the region between the facing internal electrodes are generated, the application of a voltage for the purpose of obtaining a displacement may lead to the breakdown of the actuator due to a discharge generated between the internal electrodes.

For this reason, with the conventional slit type actuator it is difficult to take out a large displacement by the application of a high voltage, so that the voltage to be applied had to be limited to low values.

Next, problems that can be generated in the use of the slit type actuator will be described.

As described in the above, to take out the displacement of the actuator to the outside it is ordinary, in general, to use the actuator by bonding its top and bottom end faces to metallic jigs 9 as shown in FIG. 3.

In that case, as the adhesive 10, use is made of a resin with high young's modulus so as not to absorb the displacement of the actuator, and it is general to use a thermosetting resin.

Accordingly, the bonding of the metallic jigs 9 to the actuator is carried out by cooling the heated state at 150 to 200 ° C to the ordinary temperatures.

In this operation, the amount of contraction at cooling in the bonding process is larger for the metallic jig because the coefficient of thermal expansion of the metallic jig 9 is greater than the coefficient of expansion of the actuator.

Because of this, compressive forces as shown by the arrows in FIG. 3 is generated in the end face of the actuator, and as a result, the inactive layer 5 is deformed as shown by the broken line in the figure.

Further, the deformation of the actuator when a voltage is applied to the actuator in the abovementioned actuator will be considered.

In FIG. 3, when a voltage is applied to the actuator, the active layer 1 is elongated in the direction of lamination due to the longitudinal electrostrictive effect and contracts in the direction perpendicular to the direction of lamination due to the lateral electrostrictive effect.

However, there will be generated no deformation in the inactive layer 5 so that the active layer 1 is urged to undergo a deformation as shown by the alternate long and short dash line in FIG. 3 (note that the elongation due to the longitudinal electrostrictive effect is not shown in the Figure).

Therefore, as the combined effect of the two kinds of deformation there is generated a large tensile stress at the interface of the active layer 1 and the inactive layer 5, that is, at the part of the internal electrode 3c of the outermost layer.

However, the strength of the actuator against tension is weaker at the interface between the ceramic and the internal electrode than in the ceramic itself which is the electrostrictive material.

Accordingly, when a high voltage is applied to the actuator of this structure for the purpose of taking out a large displacement. mechanical breakdown tends to be generated at the interface of the internal electrode 3c of the outermost layer.

As is naturally expected, similar situation occurs also at the internal electrode of the outermost layer on the opposite side (namely, on the side of the bottom end of the actuator).

Although the description in the above has been made with reference to an ordinary actuator which is not of the slit type, similar phenomenon also takes place in the slit type actuator.

For this reason, in the conventional slit type element it is necessary to limit the voltage to be applied to lower values in order to generate mechanical breakdown at the interface of the internal electrode of the outermost layer.

Summarizing the above, in the conventional slit type actuator, cracks tend to be generated in the course of the manufacturing process of the actuator, and moreover, a large tensile stress acts on the interface of the internal electrode of the outermost layer at the time of its use.

Because of this, the conventional slit type actuator has a defect in that it is necessary in its use to limit the applied voltage to a low level in order to prevent the dielectric breakdown between the internal electrodes and the external electrodes, and to prevent the mechanical breakdown of the actuator, so that it is difficult to take out a large displacement by the application of a high voltage.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a piezoelectric actuator which has a structure that can improve the aforementioned defect.

According to a first embodiment of the present invention, in a piezoelectric actuator of the type in which a layer of a material exhibiting an electrostrictive effect and a layer of internal electrode are alternately laminated, the respective internal electrodes are connected to the external electrodes in such a way that the adjacent internal electrodes mutually form facing electrodes, and grooves parallel to the internal electrodes are provided on the side face parallel to the lamination direction, the electrostrictive effect element according to the present invention is characterized in that the groove is provided on the outside, as seen in the direction of the lamination, of the outermost layer of the internal electrodes, and the layer is provided also between the internal electrode of the outermost layer and the internal electrode adjacent to it.

According to a second mode of the present invention, in a piezoelectric actuator of the type in which a layer of a material exhibiting an electrostrictive effect and a layer of internal electrode are alternately laminated, the respective internal electrodes are connected to the external electrodes in such a way that the adjacent internal electrodes mutually form facing electrodes, and grooves parallel to the internal electrodes are provided on the side face parallel to the lamination direction, the electrostrictive effect element according to the present invention is characterized in that the ends of the internal electrodes connected to one of the external electrodes are exposed to the two side faces where external electrodes are not formed.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other objects, features, and advantages of this invention will become more apparent by reference to the following detailed description of the invention, wherein:

FIG. 1A and FIG. 1B are a longitudinal sectional view and a projected view, respectively, of showing the structure of a conventional piezoelectric actuator;

FIG. 2A and FIG. 2B are a longitudinal sectional view and a side elevation, respectively, showing the structure of a conventional slit type actuator;

FIG. 3 is a diagram showing the state of bonding of the actuator to the metallic jig;

FIG. 4 is a sectional view showing the structure of a ceramic laminated body in the manufacturing process of the conventional slit type actuator;

FIG. 5 is a sectional view showing the structure of a ceramic sintered body in the manufacturing process of the conventional slit type actuator;

FIGs. 6A to 6C are a longitudinal sectional view, a side elevation, and a projected view, respectively, showing the structure of a first embodiment of the present invention;

FIG. 7 is a sectional view showing the structure of a ceramic laminated body in the manufacturing process of the first embodiment of the present invention;

FIG. 8 is a longitudinal sectional view showing the more preferable structure of a second embodiment of the present invention;

FIG. 9 is an enlarged partial sectional view for describing the deforming condition when the second embodiment of the present invention is bonded to a metallic jig and a voltage is applied; and

FIG. 10 is a chart representing the displacement characteristic for describing the effect of the second embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIGS. 6A to 6C, the slit type element according to the present embodiment has a structure in which the internal electrodes 3b connected to the external electrodes 4b are exposed to both side faces where the external electrodes 4a and 4b are not provided.

In the present embodiment, the sectional area of the slit type actuator is set to be 4 mm x 4 mm, the area of overlap of the internal electrodes 3a and 3b is set to be 3 mm x 3 mm, and each slit is formed to a depth of 0.5 mm from the side face of the actuator into its interior.

The height of the slit type element is 10 mm, the mutual distance between the internal electrodes is 0.1 mm, and the distance between a slit and an internal electrode is 0.1 mm.

In what follows the manufacturing method of the first embodiment will be described.

The first embodiment uses an electrostrictive effect material of lead magnesium niobate-lead titanate system ($0.9Pb(Mg_{1/3}\ Nb_{2/3})\ O_3$ - $0.1Pb\ TiO_3$) as the starting material, a predetermined quantities of an organic solvent, a binder, and a plasticizer are added to the calcined and pulverized powder of the starting material, and a slurry is prepared by stirring and mixing these ingredients.

The slurry is cast on a polyester film by the doctor blade method, and a green sheet with thickness of 130 μm is prepared.

After cutting the green sheet to a predetermined shape, a paste for internal electrodes having the powder of a silver-paladium alloy and a paste for slit forming material having carbon powder as the principal component are printed by application at predetermined positions by screen printing method.

A predetermined number of these green sheets are laminated in a predetermined order, and are formed into an integral body by thermocompression bonding.

FIG. 7 is a sectional view of the ceramic laminated body in the present embodiment. It has a construction in which a pattern of an internal electrode paste 11a is formed for every other layer in a continued fashion.

Because of this, a uniform pressure is easy to be applied to the portions A and the portions B of the ceramic laminated body at the time of thermocompression bonding, compared with the conventional laminated body.

Next, the ceramic laminated body obtained as in the above is treated at 600°C in the air, the binder and the slit forming material in the ceramic laminated body are removed by thermal decomposition, and a ceramic sintered body with internal vacancies is obtained by calcining it at 1100°C.

As mentioned above, according to the present embodiment there can be obtained a high quality ceramic sintered body with no generation of residual stress in the interior of the ceramic laminated body and suppressed generation of cracks during the calculation, because of the application of a uniform pressure all over at the time of thermocompression bonding and integration of the ceramic laminated body.

Finally, after cutting the ceramic laminated body at predetermined positions and applying and baking a silver paste for external electrodes on the two side faces where the internal electrodes are exposed, lead wires for voltage application are connected, completing the slit type actuator of the present embodiment.

Next, as a result of manufacturing 500 pieces each of the slit type actuators of the present embodiment obtainable as in the above, and the slit type actuator of the conventional structure, it was found that the percent defective of the former was 0 % in contrast to the percent defective of 13 % (65 pieces) of defective items with cracks for the latter.

It is to be noted that the result of displacement measurement at 150V. after subjecting a slit type actuator according to the present embodiment and a slit type actuator of the conventional structure to a polarization treatment at 150V DC for one minute, produced a value of 7.5 μm as the displacement for both kinds of actuators.

Next, the second embodiment of the present invention will be described.

FIG. 8 is a longitudinal sectional view showing the structure of the second embodiment of the slit type actuator of the present invention.

The structure of the slit type actuator of the present embodiment has a cross-sectional area of 4 mm x 4 mm, the area for the overlapping portion of the internal electrodes 3a and 3b, that is, the portion where a displacement is generated, of 3 mm x 3 mm, and the distance between the internal electrodes of 0.1 mm.

In addition, each slit 7 has a depth from the surface of 0.5 mm, and a width in the lamination direction of 5 μm.

In the present embodiment, besides the above-mentioned structure, there are provided a slit 7a at the position 50 μm outside of the internal electrode 3c of the outermost layer, and a slit 7b at a position between the internal electrode 3c of the outermost layer and the adjacent internal electrode 3d.

Similarly, slits 7c and 7d are provided on both sides of the internal electrode 3e which is the outermost layer on the bottom end side of the actuator in the figure.

Hereinafter, the structure as described in the above will be referred to as Structure I.

The above-mentioned slit type actuator was manufactured under the identical process and conditions as for the first embodiment by selecting a lead zirconate titanate system ceramic as the electrostrictive effect material.

Further, the lamination method of the ceramic laminated body, namely, the printing pattern of the internal electrodes to the green sheet is made different from that of the first embodiment, and made the same as the lamination method for the conventional slit type actuator.

In FIG. 9 is shown an enlarged partial view of a vertical section of the case when a slit type actuator of Structure I of the present embodiment is bonded to a metallic jig 9.

As can be seen from the figure, a slit 7a is provided on the further outside of the internal electrode 3c of the outermost layer. Further, a slit 7b is also provided between the internal electrode 3c of the outermost layer and the adjacent internal electrode 3d.

Of the tensile stress exerted on the interface of the internal electrode 3c the stress generated as a result of bonding to the metallic jig 9 (a force acting upward in FIG. 4) is relaxed by the presence of the slit 7a.

On the other hand, the stress which is generated as a result of applying a voltage to the slit type actuator (a force acting downward in FIG. 9) is relaxed by the presence of the slit 7b.

Because of these circumstances, mechanical breakdown at the interface of the internal electrode 3c of the outermost layer is made less likely to occur.

Next, in order to confirm the effect of the present invention, the top and the bottom ends of a slit type actuator obtained as in the above are bonded to stainless steel metallic jigs using an epoxy adhesive, and cured at 150 °C.

On the other hand, for the purpose of comparison, a slit type actuator of the conventional structure in which the slits 7a, 7b, 7c, and 7d are devoid of the slit type actuator of the present embodiment was also subjected to a similar processing.

Subsequently, after giving a polarization treatment at 150V DC for one minute for 20 pieces each of the respective kinds of the slit type actuator, the change in the displacement for the case of application of a voltage at a rate of voltage increase of 100 V/min (DC) was investigated for each kind.

The result of the test is shown in FIG. 10.

In contrast to the occurrence of mechanical breakdown in the range of 240 to 290 V for the conventional slit type actuator, the breakdown voltage was raised to the range of 620 to 690 V for the slit type actuator according to the present embodi-

ment. As a result, a larger displacement was obtained for the slit type actuator of the present embodiment compared with the conventional slit type actuator.

Moreover, by manufacturing 20 pieces of a slit type actuator with a structure that has additionally one slit each at positions by 100 μm outside of the slits 7a and 7c of the slit type actuator of Structure I shown in FIG. 6 (referred to as Structure II hereinafter), a voltage was applied in the same way as for the slit type actuator of Structure I. In this case, the breakdown voltage was further enhanced to the range of 720 to 780 V as shown in FIG. 10.

This result is considered due to a further reduction, brought about by the increase in the number of slits provided, in the tensile stress generated at the interfaces of the internal electrodes of the outermost layers by the bonding of the actuator to the metallic jigs.

As in the above, according to the first mode of the present invention, a ceramic laminated body with no internal residual stress can be obtained, and a high quality ceramic sintered body with no internal crcaks can be obtained by calcining the laminated body. Therefore, it is possible to manufacture with high yield a highly reliable slit type actuator which enables one to take out a large displacement by the application of a high voltage.

Moreover, according to the second mode of the present invention, in the slit type element it is possible to relax the tensile stress generated in the interface of the internal electrode of the outermost layer, at the time of application of a voltage by bonding metallic jigs for taking out the displacement, by providing slits at the positions further outside of the internal electrodes of the outermost layers, and providing slits between the internal electrodes of the outermost layers and the respective adjacent internal electrodes. Therefore, the breakdown voltage that leads to mechanical breakdown can be made higher, and hence a slit type actuator that enables one to take out a large displacement can be obtained.

Although the invention has been described with reference to specific embodiments, this description is not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as other embodiments of the invention, will become apparent to persons skilled in the art upon reference to the description of the invention. It is therefore contemplated that the appended claims will cover any modifications or embodiments as fall within the true scope of the invention.

Claims

1. A piezoelectric actuator comprising: a pillar of piezoelectric material having a side surfaces extending between top and bottom surfaces thereof, a first group of internal electrode layers embedded within said pillar, each of said first group of internal electrode layers being spaced apart from each other but electrically connected to a first external electrode, a second group of internal electrode layers embedded within said pillar so as to be respectively sandwiched between said first group of internal electrode layers and commonly connected to a second external electrode, a plurality of grooves formed on said side surface so as to surround an elongated axis of said pillar, each of a pair of outermost internal electrode layers being located between a pair of said grooves which are located outermost portion of said pillar.

2. The piezoelectric actuator as claimed in claim 1, wherein said pillar has a rectangular shape so as to have four side surfaces, ends of said first and second group of internal electrode layers are lead out from two of said four side surfaces so as to be connected to said first and second external electrodes, respectively, and a pair of opposed ends of said first group internal electrode layers are exposed from remaining two of said four side surfaces.

3. The piezoelectric actuator as claimed in claim 1, further comprising a pair of additional grooves which are respectively provided between outermost grooves and said top and bottom surfaces.

4. A piezoelectric actuator comprising: a plurality of electrostrictive effect layers, a plurality of internal electrode layers respectively sandwiched between said electrostrictive effect layers, two external electrodes alternately connected to said internal electrodes, and a plurality of grooves provided on the side surface of a laminated body of said electrostrictive effect layers and said internal electrode layers such that each of said grooves extends along the direction parallel to a principal surface of said internal electrode layers, each of the outermost internal electrode layers being located between a pair of said grooves.

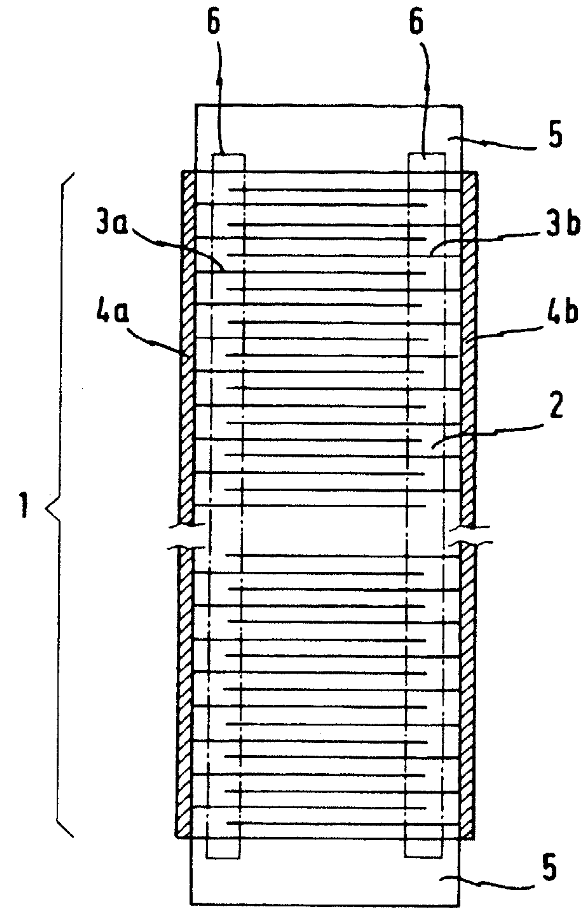


FIG. 1A

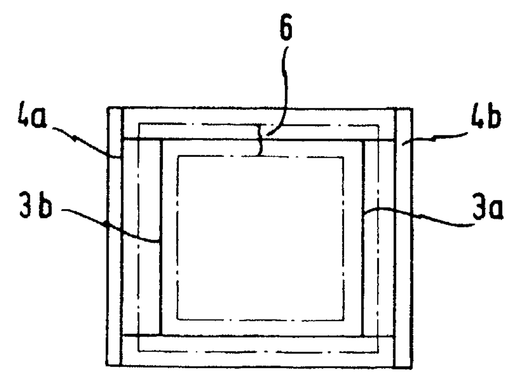


FIG. 1B

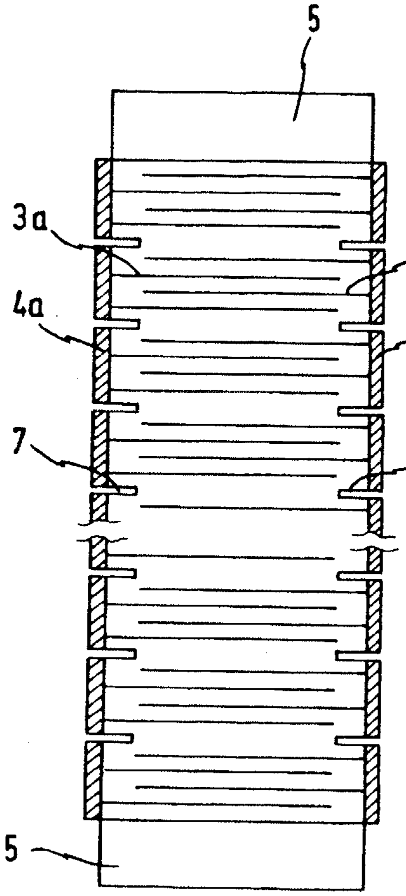


FIG. 2A

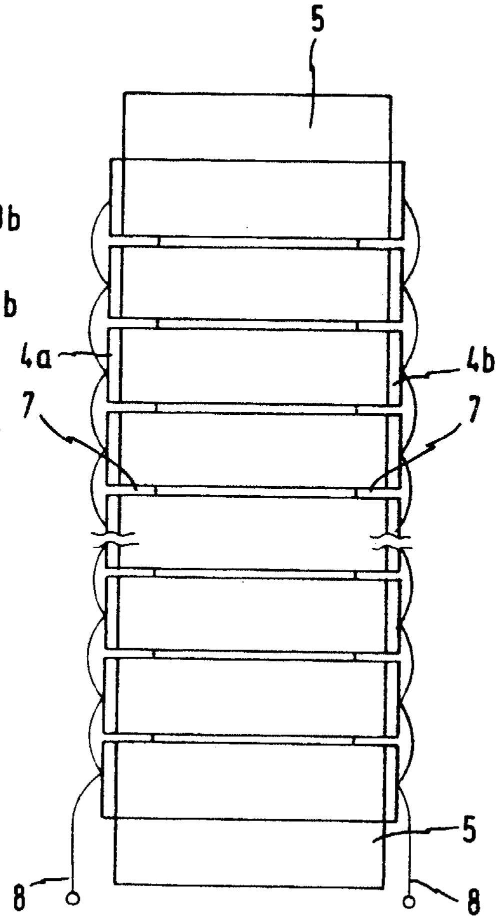


FIG. 2B

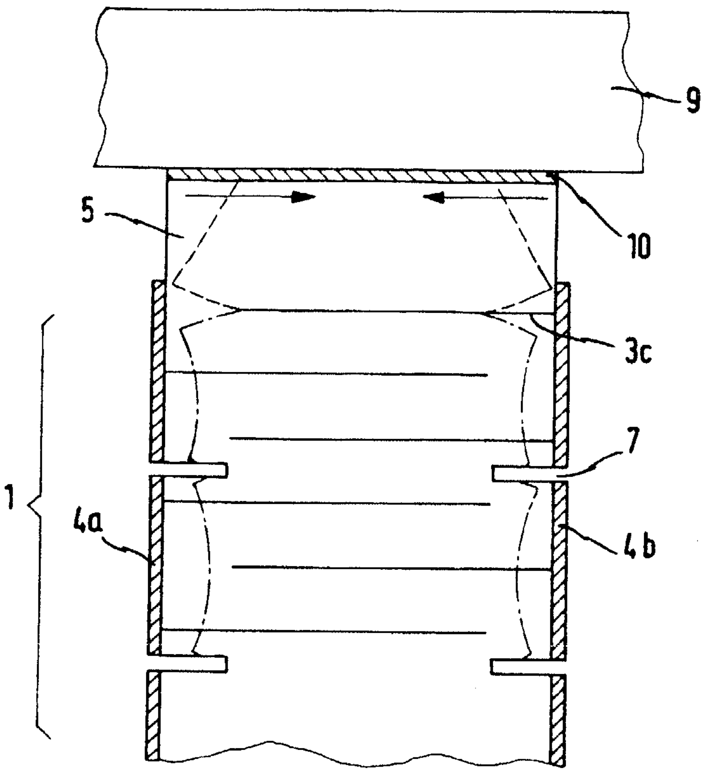


FIG. 3

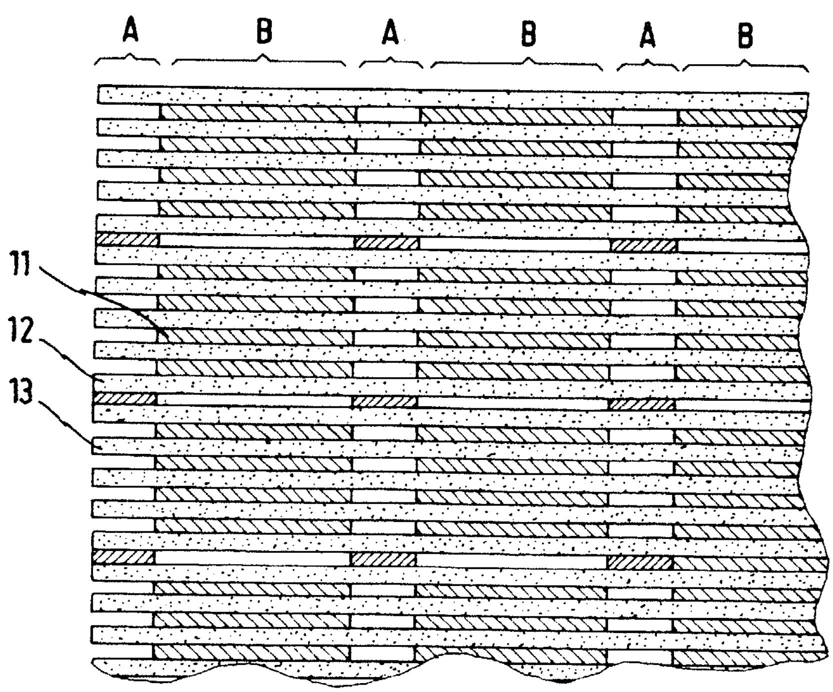


FIG. 4

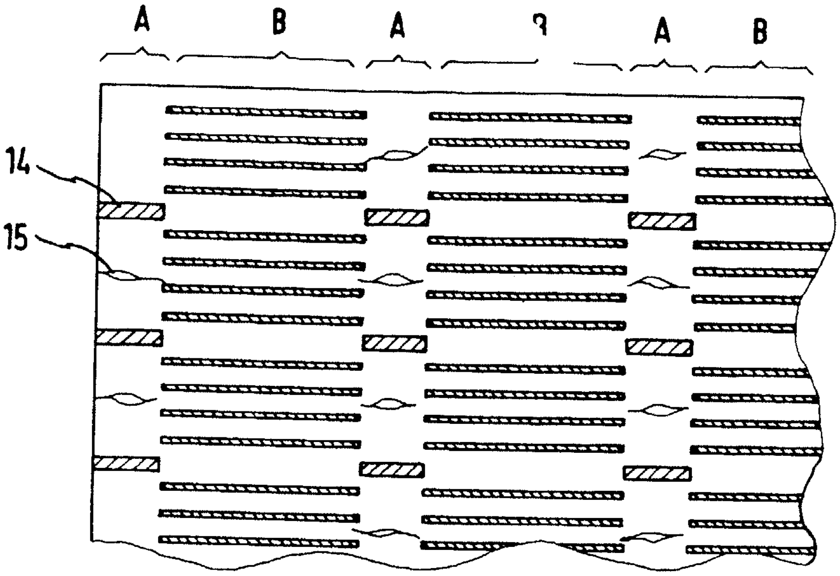


FIG. 5

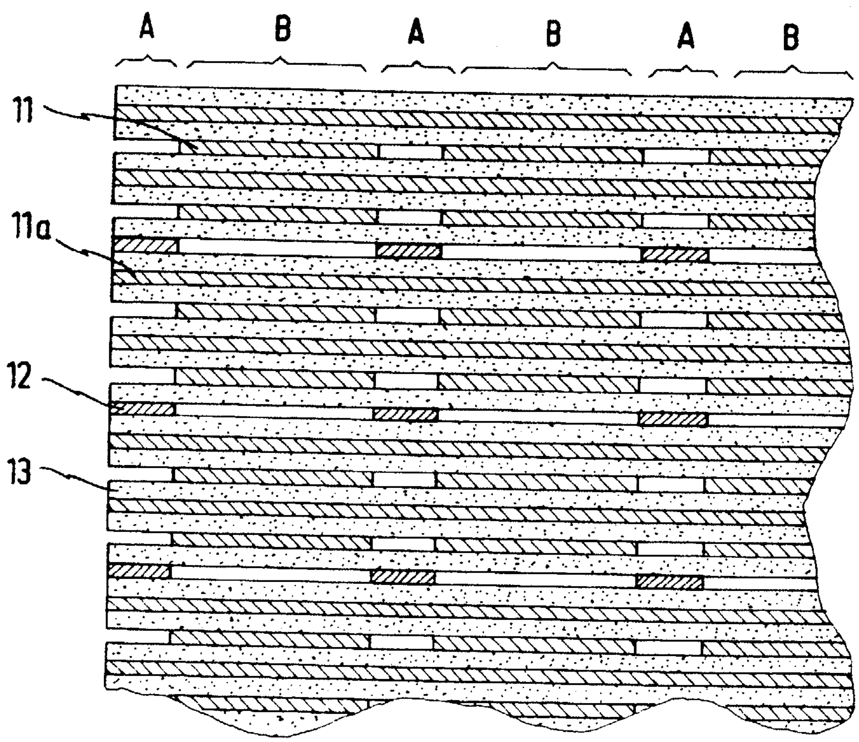
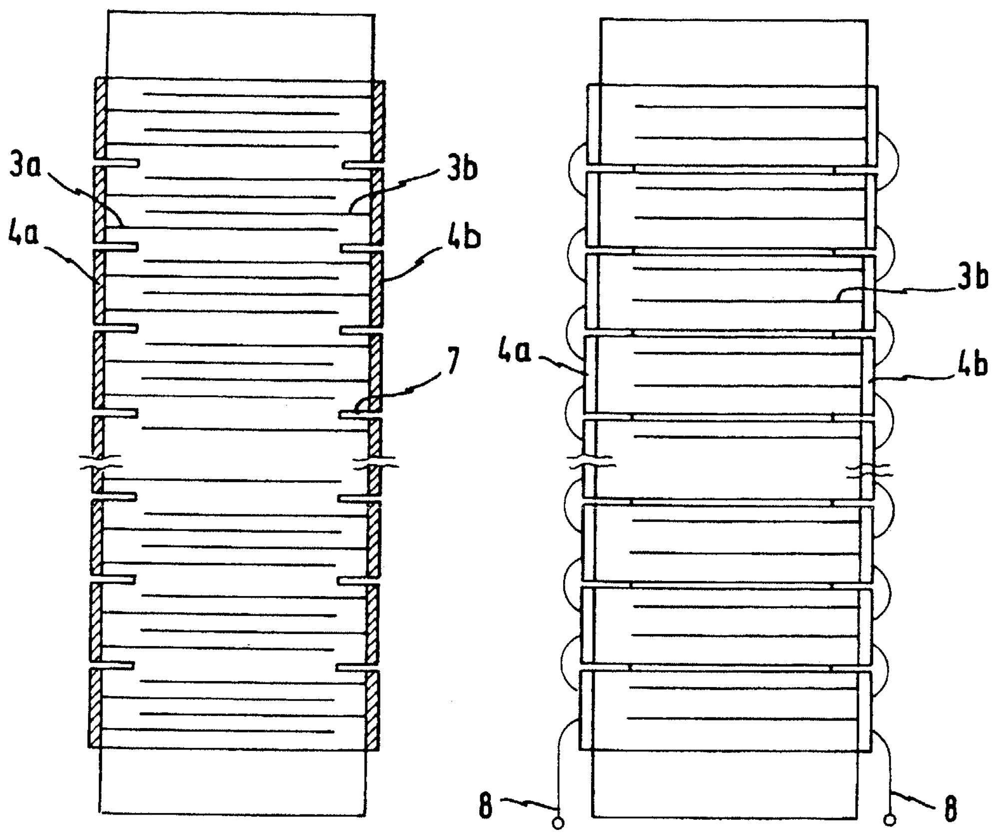


FIG. 7

FIG. 6A

FIG. 6B



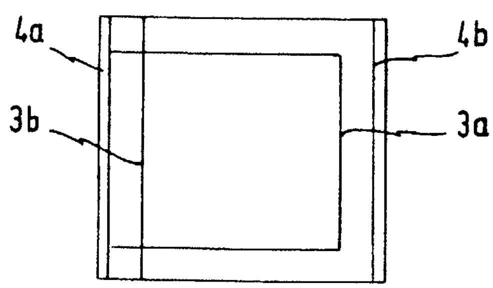
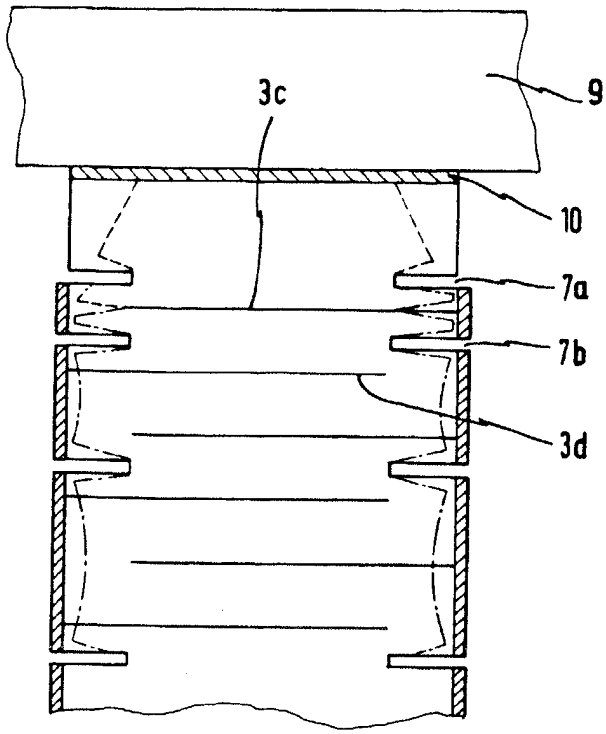


FIG. 6C

FIG. 9


3c
9
10
7a
7b
3d

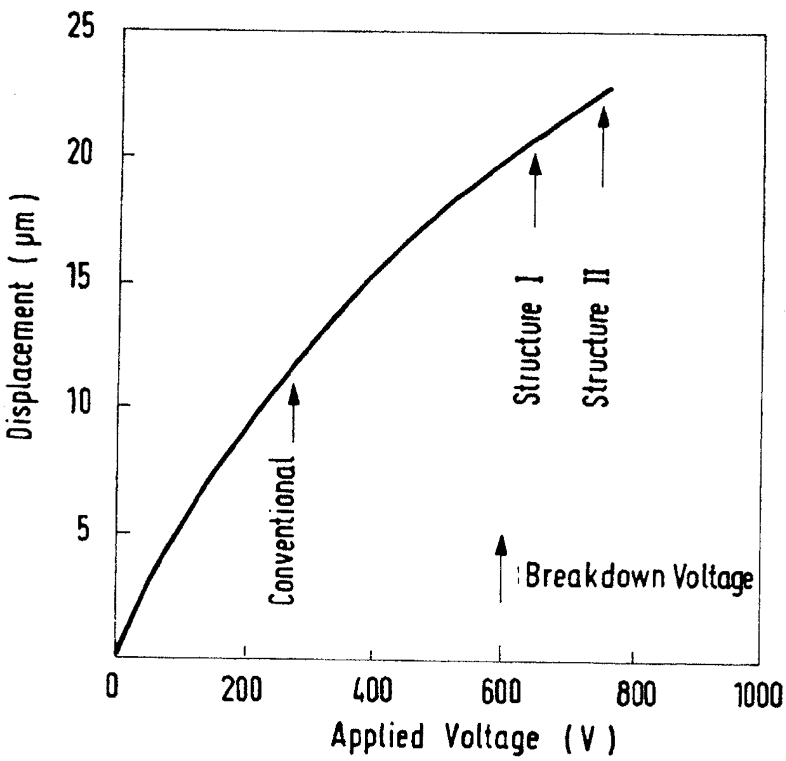

25
20
15
10
5
0
200
400
600
800
1000
Displacement (μm)
Applied Voltage (V)
Conventional
Structure I
Structure II
:Breakdown Voltage

FIG. 10

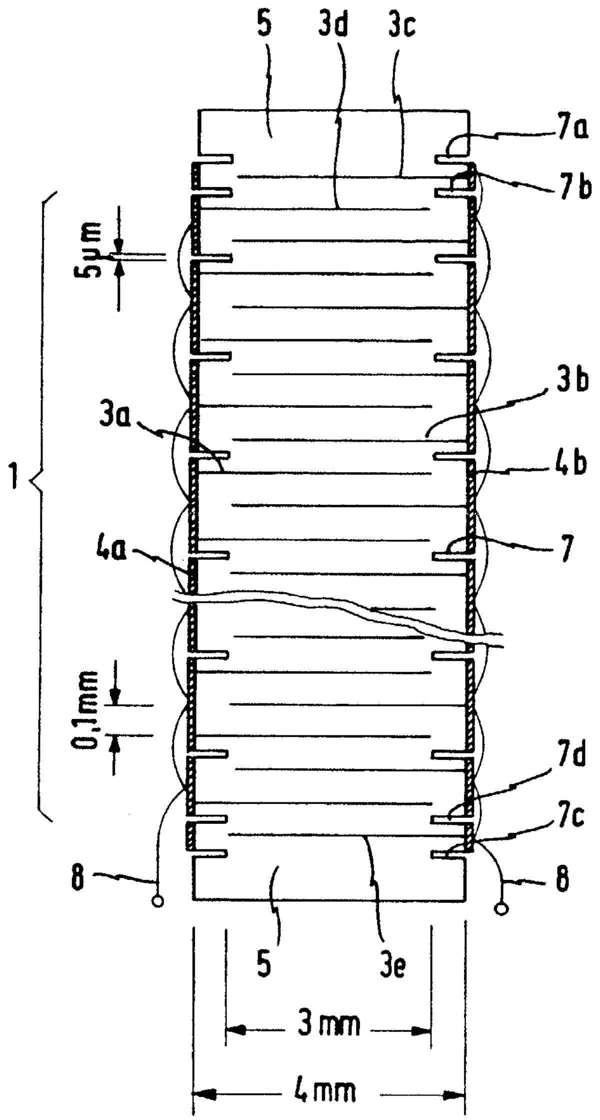


FIG. 8

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(54) **Piezoelectric actuator.**

(57) In a piezoelectric actuator of the type which has a plurality of grooves on the outer side surface of the actuator body, mechanical reliability of the actuator is enhanced by providing grooves also in the respective layers of a material exhibiting electrostrictive effect located over and below the top and the bottom ends of the actuator. Moreover, a further improvement of mechanical strength can be attained by providing additional grooves onto the outer most grooves.

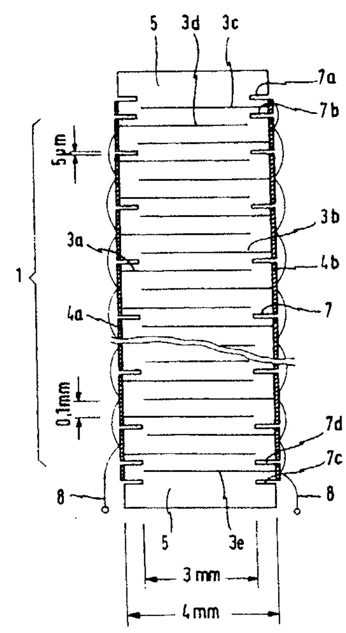

FIG. 8

EP 0 479 328 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 11 7052

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,A	EP-A-0 094 078 (NEC CORPORATION) * the whole document * ---	1-4	H01L41/08
P,A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 200 (E-1070)22 May 1991 & JP-A-3 053 572 (NEC CORPORATION) 7 March 1991 * abstract * ---	1-4	
P,A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 355 (E-1109)9 September 1991 & JP-A-3 138 987 (NEC CORPORATION) 13 June 1991 * abstract * -----	1-4	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09 JUNE 1992	PELSERS L.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

US005266862A

United States Patent [19]

Ohya

[11] Patent Number: 5,266,862

[45] Date of Patent: Nov. 30, 1993

[54] PIEZOELECTRIC ACTUATOR

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[73] Assignee: NEC Corporation, Tokyo, Japan

[21] Appl. No.: 780,779

[22] Filed: Oct. 23, 1991

[30] Foreign Application Priority Data

Oct. 23, 1990 [JP] Japan 2-284843

[51] Int. Cl.^{5} H01L 41/08

[52] U.S. Cl. 310/328; 310/366

[58] Field of Search 310/366, 328

[56] References Cited

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Primary Examiner—Mark O. Budd
Assistant Examiner—Thomas M. Dougherty
Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis

[57] ABSTRACT

In order to make uniform and smooth elongation of a piezoelectric actuator at the end faces thereof, at least one piezoelectric active layer with at least one non-conductive area formed at the central portion thereof is arranged between an inactive layer and an extreme piezoelectric active layer of the element.

5 Claims, 6 Drawing Sheets

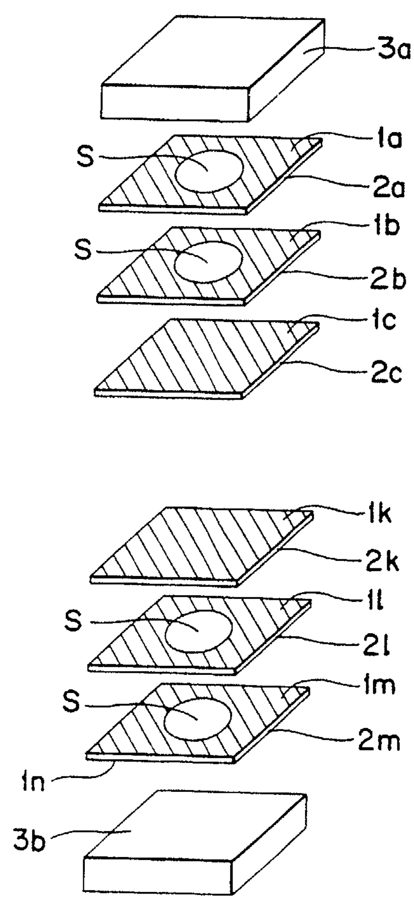


FIG. 1
PRIOR ART

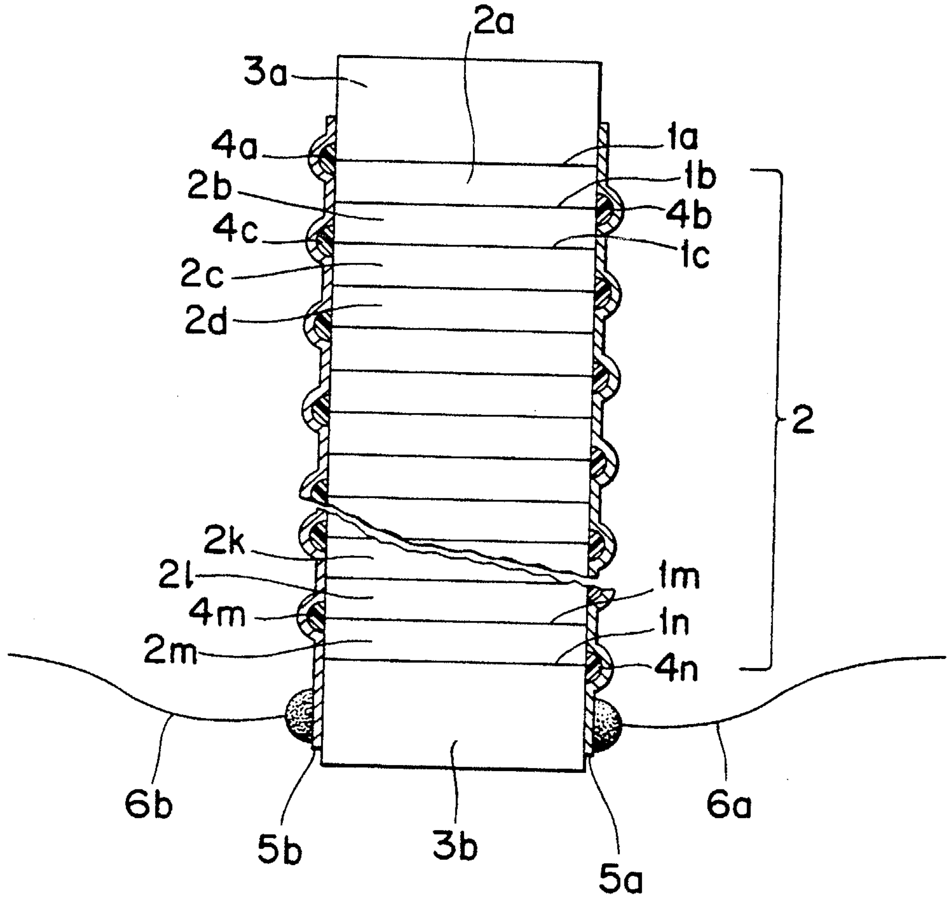


FIG. 2
PRIOR ART

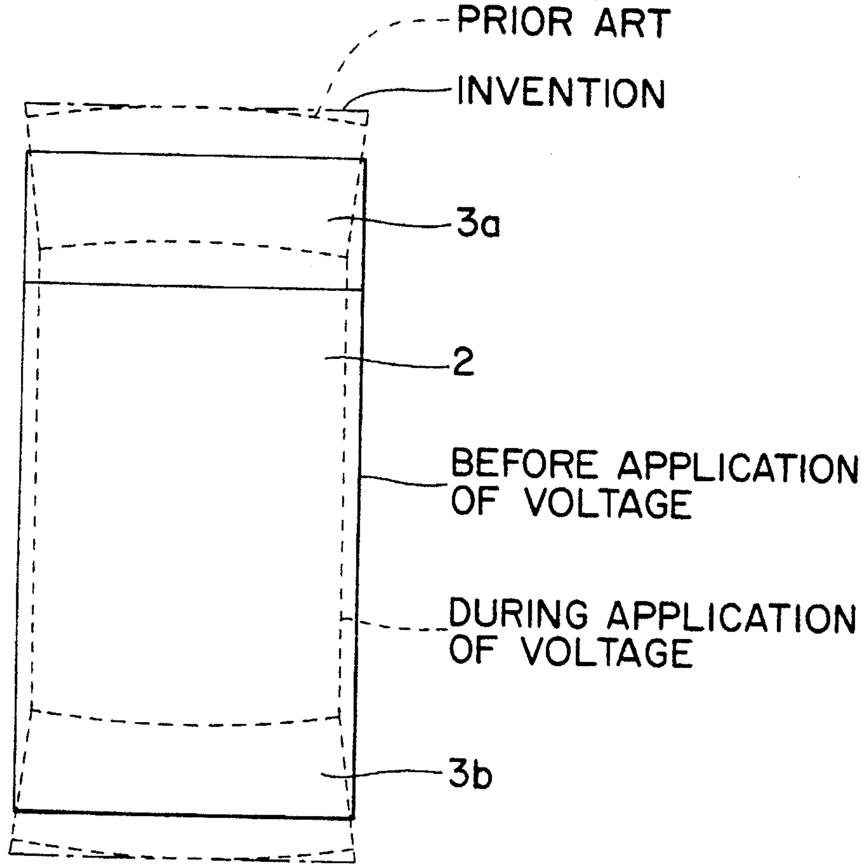


FIG. 3

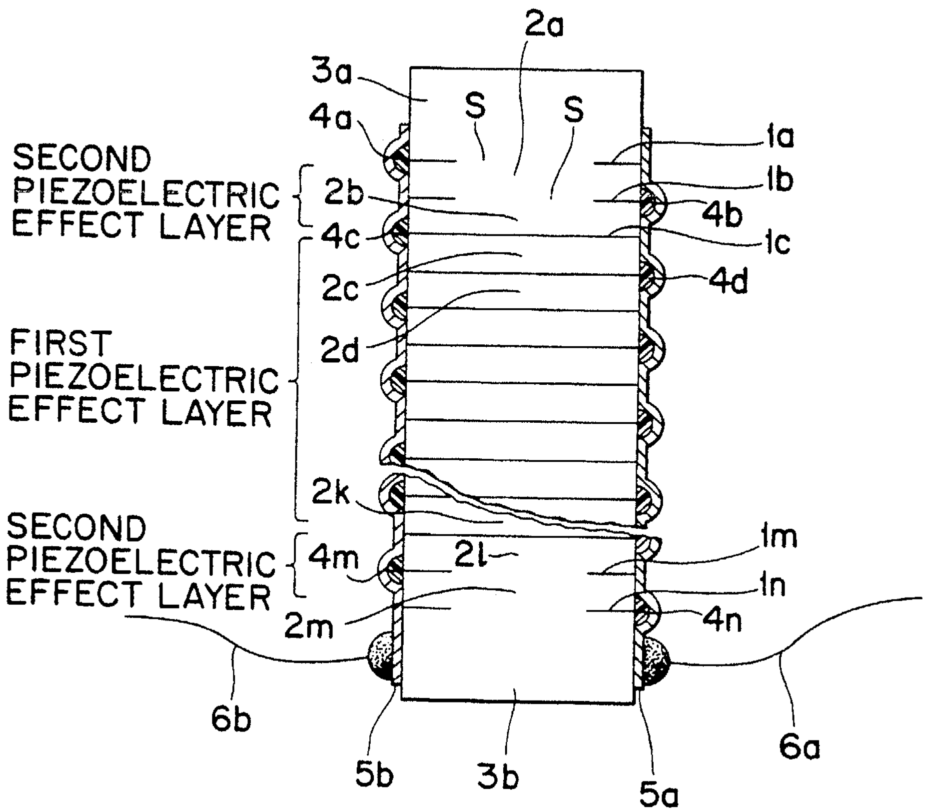

2a
3a
4a
S
S
1a
1b
SECOND PIEZOELECTRIC EFFECT LAYER
2b
4b
4c
1c
2c
4d
FIRST PIEZOELECTRIC EFFECT LAYER
2d
2k
SECOND PIEZOELECTRIC EFFECT LAYER
1m
4m
2l
1n
4n
2m
6b
6a
5b
3b
5a

FIG. 4

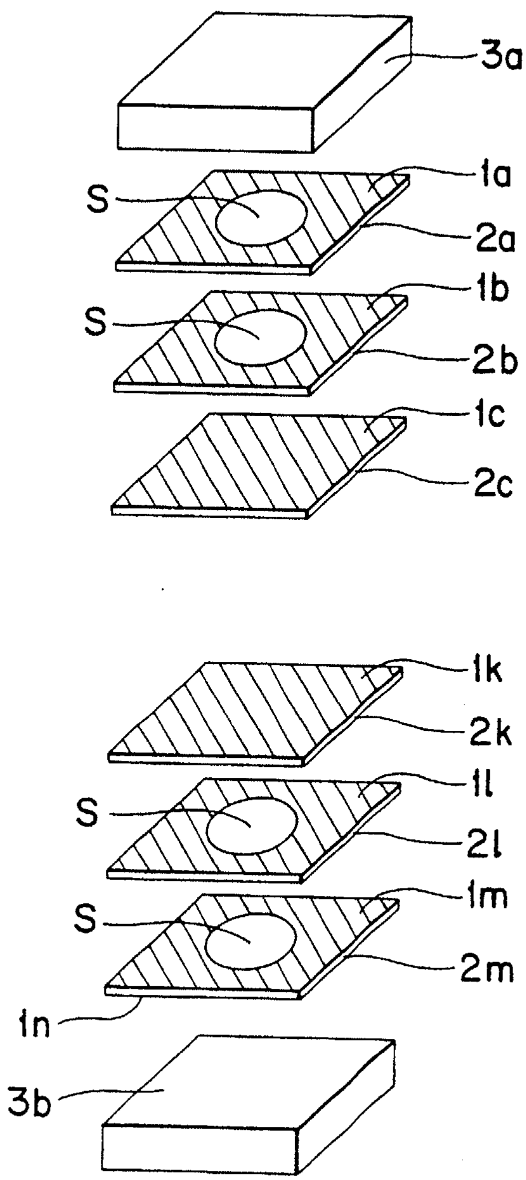


FIG. 5

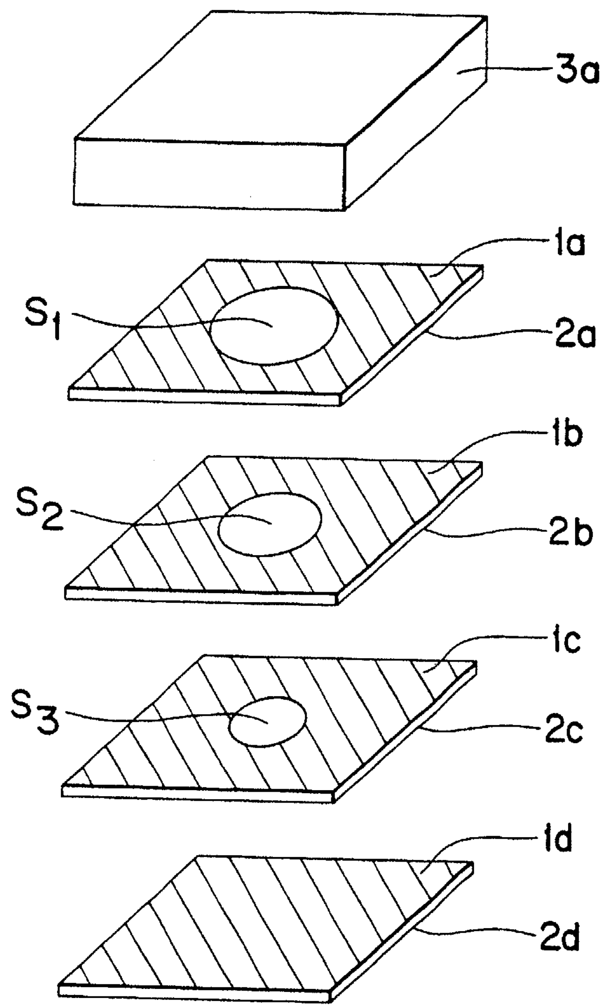


FIG. 6A

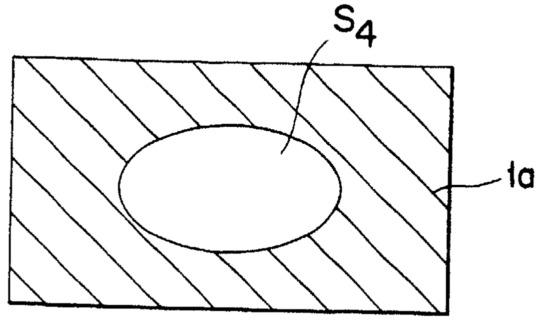


FIG. 6B

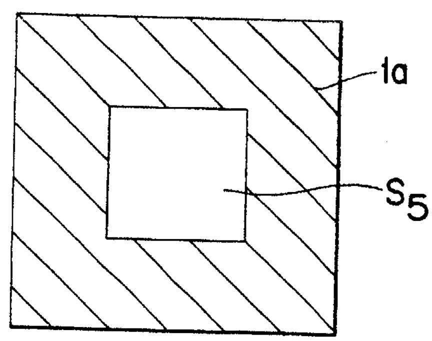


FIG. 6C

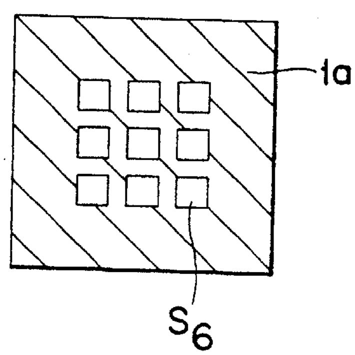
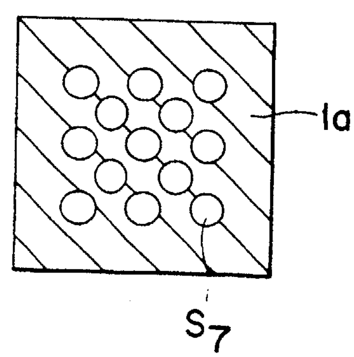


FIG. 6D



PIEZOELECTRIC ACTUATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a piezoelectric actuator utilizing an electrostrictive lengthwise effect which is suitable for use in piezoelectric actuators.

2. Description of the Prior Art

A piezoelectric actuator is designed to obtain a minute mechanical displacement utilizing a piezoelectric actuator (hereinafter referred to as "actuator") which can convert electric energy into mechanical energy and is used in the field of applications which require precise control of movement of a minute position, such as a mass flow controller used in manufacturing apparatus of semiconductor IC circuits, an X-Y table used in exposure systems for the manufacture of the IC circuits, plastics injection molding machines and so on.

One of such a type of conventional piezoelectric actuators is described in Japanese Journal of Applied Physics, Vol. 24 (1985), Supplement 24–3, pp. 209–212.

As shown in FIG. **1**, the prior art piezoelectric actuator comprises a laminated sintered member including a plurality of piezoelectric active layers (hereinafter referred to as "active layer") **2***a*, **2***b*, **2***c*, **2***d* . . . **2***k*, **2***l* and **2***m*, each layer being made of an electrostrictive ceramic material, a plurality of internal electrodes **1***a*, **1***b*, **1***c* . . . **1***m* and **1***n* made of silver, palladium alloy or platinum, each of which is placed between each pair of piezoelectric active layers, and inactive layers **3***a* and **3***b* each in the form of thicker electrostrictive ceramic sheet, these inactive layers **3***a* and **3***b* being located to cover the opposite ends of the laminated sintered member. The laminated sintered member also comprises insulating layers **4***a*, **4***b*, **4***c* . . . **4***m* and **4***n* of glass or the like disposed to insulate the internal electrodes **1***a*, **1***b* . . . **1***n* on alternate layers; a pair of external electrodes **5***a* and **5***b* disposed at opposite sides of the laminated sintered member and disposed to perform electric connection on alternate internal electrodes; and a pair of leads **6***a* and **6***b* electrically connected with the external electrodes **5***a* and **5***b*, respectively.

In such an arrangement, the piezoelectric active layer assembly **2** is expanded in its longitudinal direction and contracted in a direction perpendicular to said longitudinal direction when an electric field is applied to the piezoelectric actuator. On the other hand, the inactive layers **3***a* and **3***b* are not subject to any piezoelectric effect. As a result, the piezoelectric active layer assembly **2** is brought into intense engagement with the inactive layers **3***a* and **3***b*. Since the piezoelectric active layer assembly **2** is incorporated integrally between the inactive layers **3***a* and **3***b*, the piezoelectric actuator is deformed without slippage at the interface between each pair of adjacent layers. As a result, the opposite end faces of the piezoelectric actuator will be bulged outwardly, as shown in FIG. **2**.

This will create uneven strain in the piezoelectric actuator.

The uneven strain may be overcome if the opposite end faces of the piezoelectric actuator are adhered to any smooth fixed surfaces. However, this may cause internal stress in the piezoelectric actuator and, in the worst case, may break the element.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to overcome the disadvantages of the prior art and to provide a piezoelectric actuator in which elongation of the actuator at the end faces thereof is made uniform and smooth and which can prevent any damage due to any internal stress partially created therein.

To this end, the present invention provides a piezoelectric actuator comprising first piezoelectric active layers including electrostrictive ceramic members and internal electrodes which are alternately laminated one on another and inactive layers creating no piezoelectric effect and being located on the first piezoelectric active layer on the opposite ends thereof in the direction of lamination, said actuator being characterized by at least one second piezoelectric active layer disposed between each of the inactive layers and the first piezoelectric active layer, the second piezoelectric active layer also serving as an internal electrode which has a non-conductive area thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal cross-section of a piezoelectric actuator constructed in accordance with the prior art.

FIG. **2** is a view illustrating deformation of a piezoelectric actuator due to the pizoelectric effect according to the prior art and the present invention.

FIG. **3** is a longitudinal cross-section of one embodiment of a piezoelectric actuator fabricated in accordance with the present invention.

FIG. **4** is an exploded perspective view illustrating one type of internal electrodes used in the piezoelectric actuator shown in FIG. **3**.

FIG. **5** is a view similar to FIG. **4**, illustrating another type of internal electrode usable in the piezoelectic actuator of the present invention.

FIGS. **6**A, **6**B, **6**C and **6**D show various other types of internal electrodes usable in the piezoelectric actuator of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described with reference to the drawings.

FIG. **3** is a longitudinal cross-section of one embodiment of a piezoelectric actuator fabricated in accordance with the present invention while FIG. **4** is an exploded perspective view illustrating one type of internal electrodes used in the piezoelectric actuator shown in FIG. **3**. In FIG. **3**, parts similar to those of FIG. **1** are designated by similar reference numerals.

First of all, an organic solvent binder and plasticizing material are added to and mixed with a calcinated powder of electrostrictive material such as titanic acid, lead zirconate, nickel lead niobate or the like. The resulting slurry is formed into a green sheet having a thickness of about 130 μm by the use of a doctor blade process. As shown in FIG. **4**, a conductive paste containing powdered silver-palladium alloy or platinum is screen printed on a laminated sintered member while leaving non-conductive areas S on piezoelectric active layers **2***a* and **2***b* adjacent to the top of the laminated sintered member and piezoelectric active layers **2***m* and **2***l* (which layers will be referred to "second piezoelectric active layers") adjacent to the bottom of the laminated sintered member at their central portions. The conduc-

tive paste is screen printed on the other piezoelectric active layers **2**c, **2**d . . . **2**k (which will be referred to as "first piezoelectric active layers") over the entire surface areas thereof. In this embodiment, the cross-section of the piezoelectric actuator is of a square configuration of 10 mm×10 mm while each of the non-conductive areas S is in the form of a circle having a diameter of 8 mm.

The inactive layers **3**a and **3**b may be formed of the same material as that of the piezoelectric active layers **2**a to **2**m. After the piezoelectric active layers **2**a to **2**m and the inactive layers **3**a and **3**b have been laminated, the resulting lamination is pressed under heat and pressure to form an integral member. After buring out the binder, the integral member is fired for three hours at 1000° C. to provide a laminated sintered member as shown in FIG. **3**.

The conductive paste layers sandwiched between each pair of adjacent piezoelectric active layers will form internal electrodes **1**a, **1**b, **1**c . . . **1**m and **1**n.

The outer edges of the internal electrodes **1**a, **1**b . . . **1**n expose outwardly at the opposite sides of the laminated sintered member thus formed. These outer exposed edges of the internal electrodes are alternately covered with insulating layers **4**a, **4**b, **4**c, **4**d . . . **4**m and **4**n each of which is formed by depositing and baking powdered glass on the corresponding edge using the electrical migration. Subsequently, a pair of external electrodes **5**a and **5**b are formed by applying and baking a conductive paste containing powdered silver and glass on the opposite sides of the laminated sintered member so that the internal electrodes **1**a, **1**b, . . . **1**n will be electrically connected together on alternate layers. The product is completed when a pair of leads **6**a and **6**b are electrically connected with the external electrodes **5**a and **5**b, respectively.

FIG. **5** shows the other types of internal electrode usable in the piezoelectric actuator of the present invention. In this drawing, only the internal electrodes of the piezoelectric actuator adjacent one (top) end thereof are shown for simplicity. The cross-section of this piezoelectric actuator is of a square shape of 15 mm×15 mm. The internal electrodes **1**a, **1**b and **1**c have non-conductive areas S_1, S_2, and S_3 having diameters of 13 mm, 10 mm and 8 mm, respectively. The material and its thickness are the same as those of the previous embodiment shown in FIG. **4**.

The embodiment shown in FIG. **5** can be applied to piezoelectric actuators of larger sizes since the central non-conductive areas S_1 to S_3 on the internal electrodes are different from one another. At the same time, the profile of strain at the opposite ends of the piezoelectric actuator can be be diminished.

Although two different kinds of internal electrodes have been described as to a single circular non-conductive area on a single internal electrode, a single elliptic area S_4 or a polygonal non-conductive area S_5 may be provided on an internal electrode as shown in FIG. **6**A or **6**B or a plurality of areas S_7 or polygonal non-conductive areas S_6 may be provided on the same internal electrode as shown in FIG. **6**C or **6**D.

From the foregoing, it will be apparent that the piezoelectric actuator of the present invention has a reduced elongation at the central portion in comparison with that of the peripheral portion by adding the second piezoelectric active layers onto the opposite ends of the first piezoelectric active layers, the second piezoelectric active layers having internal electrodes formed with the central non-conductive areas. If such central non-conductive areas are not provided therein, the outer ends of the inactive layers could be bulged outwardly to increase elongation at the central portion. Thus, the second piezoelectric active layers make the elongation at the opposite ends of the element uniform and smooth. In addition, any breaking-down of the element can be prevented by the second piezoelectric active layers.

What is claimed is:

1. A piezoelectric actuator comprising:

first piezoelectric active layers including an alternate lamination of electrostrictive ceramic materials and internal electrodes;

a pair of inactive layers respectively disposed at the opposite ends of said piezoelectric actuator in the direction of lamination; and

at least one second piezoelectric active layer sandwiched between an end of each inactive layer of said pair of inactive layers and an end of said first piezoelectric active layers, each said second piezoelectric active layer including a non-conductive area formed thereon at the central portion.

2. A piezoelectric actuator according to claim **1**, wherein the non-conductive area of said at least one second piezoelectric active layer is of a circular, elliptic or polygonal configuration.

3. A piezoelectric actuator according to claim **1**, wherein each said second piezoelectric active layer has a non-conductive area of the same configuration.

4. A piezoelectric actuator according to claim **1**, wherein the non-conductive area of each said second piezoelectric active layer has a smaller size as the second piezoelectric active layer is located further from an inactive layer.

5. A piezoelectric actuator according to claim **1**, wherein said at least one second piezoelectric active layer includes a plurality of non-conductive areas.

* * * * *

(12) NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT) VERÖFFENTLICHTE INTERNATIONALE ANMELDUNG

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Internationales Büro

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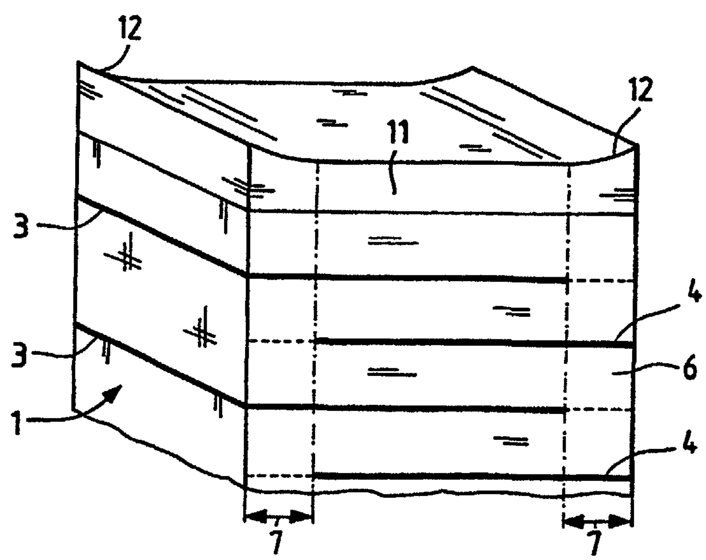
Veröffentlicht:

— *Mit internationalem Recherchenbericht.*
— *Vor Ablauf der für Änderungen der Ansprüche geltenden Frist; Veröffentlichung wird wiederholt, falls Änderungen eintreffen.*

[Fortsetzung auf der nächsten Seite]

(54) **Title:** PIEZO-ACTUATOR

(54) **Bezeichnung:** PIEZOAKTOR



(57) **Abstract:** The invention relates to a piezo-actuator, for example, for actuating a mechanical component. The inventive piezo-actuator is provided with a multilayer structure of piezo-layers (2) and electrodes (3, 4) arranged therebetween. In the instance of a mutual lateral contacting (5, 6) of the electrodes (3, 4), a neutral phase (7) without an electrode layer is provided, in which fissuring can occur and can be prevented by shaping the multilayer structure thus enabling an increased mechanical stress to be applied in the area of the neutral phases (7) when the piezo-actuator (1) is mounted in a manner that is perpendicular to the layer structure.

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Zur Erklärung der Zweibuchstaben-Codes, und der anderen Abkürzungen wird auf die Erklärungen ("Guidance Notes on Codes and Abbreviations") am Anfang jeder regulären Ausgabe der PCT-Gazette verwiesen.

(57) Zusammenfassung: Es wird ein Piezoaktor, beispielsweise zur Betätigung eines mechanischen Bauteils vorgeschlagen, bei dem ein Mehrschichtaufbau von Piezolagen (2) und dazwischen angeordneten Elektroden (3, 4) angeordnet ist. Bei einer wechselseitigen seitlichen Kontaktierung (5, 6) der Elektroden (3, 4) ist eine neutrale Phase (7) ohne Elektrodenschicht vorhanden, in der Rissbildungen entstehen können, die durch eine Formgebung des Mehrschichtaufbaus verhindert werden können, über die eine erhöhte mechanische Spannung, bei einer Einspannung des Piezoaktors (1) senkrecht zum Lagenaufbau, im Bereich der neutralen Phasen (7) aufbringbar ist.

Piezoaktor

Stand der Technik

Die Erfindung betrifft einen Piezoaktor, beispielsweise zur Betätigung eines mechanischen Bauteils wie ein Ventil oder dergleichen, nach den gattungsgemäßen Merkmalen des Hauptanspruchs.

Es ist allgemein bekannt, dass unter Ausnutzung des sogenannten Piezoeffekts ein Piezoelement aus einem Material mit einer geeigneten Kristallstruktur aufgebaut werden kann. Bei Anlage einer äußeren elektrischen Spannung erfolgt eine mechanische Reaktion des Piezoelements, die in Abhängigkeit von der Kristallstruktur und der Anlagebereiche der elektrischen Spannung einen Druck oder Zug in eine vorgebbare Richtung darstellt. Der Aufbau dieses Piezoaktors kann hier in mehreren Schichten erfolgen

(Multilayer-Aktoren), wobei die Elektroden, über die die elektrische Spannung aufgebracht wird, jeweils zwischen den Schichten angeordnet werden. Beim Betrieb des Piezoaktors ist darauf zu achten das durch mechanische Spannungen im Lagenaufbau keine störenden Rissbildungen entstehen.

Vorteile der Erfindung

Der eingangs beschriebene Piezoaktor, der beispielsweise zur Betätigung eines mechanischen Bauteils verwendbar sein kann, ist in vorteilhafter Weise mit einem Mehrschichtaufbau von Piezolagen und dazwischen angeordneten Elektroden aufgebaut. Bei einer wechselseitigen seitlichen Kontaktierung der Elektroden entsteht im Bereich zwischen zwei Piezolagen jeweils eine neutrale Phase. Da die jeweils an einer Seite kontaktierten Elektroden kammartig in den Lagenaufbau integriert sind, müssen die in Richtung des Lagenaufbaus aufeinanderfolgenden Elektroden jeweils abwechseln an gegenüberliegen Seiten kontaktiert werden.

Die an einer Seite kontaktierten Elektroden können dabei nicht vollständig bis an die gegenüberliegende Seite geführt werden, da sonst Spannungsüberschläge zur Zerstörung des Piezoaktors führen können. Bei einer Betätigung des Piezoaktors, d.h. bei Anlage einer Spannung zwischen den im Lagenaufbau gegenüberliegenden Elektroden treten unterschiedliche mechanische Kräfte im Bereich der Elektroden sowie in den nichtkontaktierten neutralen Phasen auf, die zu mechanischen Spannungen und Rissbildungen im Piezoaktor führen können.

In vorteilhafter Weise wird erfindungsgemäß bei einer Einspannung des Piezoaktors senkrecht zum Lagenaufbau mit

einer Formgebung des Mehrschichtaufbaus gezielt eine erhöhte mechanische Spannung im Bereich der neutralen Phasen zur Verhinderung der Rissbildung aufgebracht.

Bei einer ersten vorteilhaften Ausführungsform ist mindestens eine äußere Deckschicht des Mehrschichtaufbaus an der äußeren Endfläche so gestaltet, dass diese im Bereich der neutralen Phasen eine Verdickung aufweist und so hier gezielt eine erhöhte Vorspannkraft aufgebracht werden kann. Die Verdickung kann auf einfache Weise beispielsweise durch Schleifen der Deckschicht gebildet werden.

Bei einer anderen vorteilhaften Ausführungsform wird zwischen den Lagen des Mehrschichtaufbaus eine Isolationsschicht angeordnet, die im Bereich der neutralen Phasen jeweils eine Verdickung aufweist und so in vergleichbarer Weise wie beim ersten Ausführungsbeispiel wirkt.

Eine weitere Ausführungsform weist in vorteilhafter Weise besonders gestaltete Elektroden im Mehrschichtaufbau auf, die ebenfalls im Bereich der neutralen Phase jeweils eine Verdickung aufweisen, wobei hinsichtlich der verschiedenen zuvor genannten Ausführungsformen auch einige oder alle Merkmale miteinander kombiniert sind.

Diese und weitere Merkmale von bevorzugten Weiterbildungen der Erfindung gehen außer aus den Ansprüchen auch aus der Beschreibung und den Zeichnungen hervor, wobei die einzelnen Merkmale jeweils für sich allein oder zu mehreren in Form von Unterkombinationen bei der Ausführungsform der Erfindung und auf anderen Gebieten verwirklicht sein und vorteilhafte sowie für sich schutzfähige Ausführungen darstellen können, für die hier Schutz beansprucht wird.

Zeichnung

Ausführungsbeispiele des erfindungsgemäßen Piezoaktors werden anhand der Zeichnung erläutert. Es zeigen:

Figur 1 einen Schnitt durch einen Piezoaktor mit einem Mehrschichtaufbau von Lagen aus Piezokeramik und Elektroden;

Figur 2 einen Detailschnitt durch den Lagenaufbau im Bereich von neutralen Phasen ohne Anlage einer elektrischen Spannung;

Figur 3 einen Detailschnitt durch den Lagenaufbau im Bereich von neutralen Phasen mit Anlage einer elektrischen Spannung;

Figur 4 ein erstes Ausführungsbeispiel eines Piezoaktors, bei dem eine äußere Deckschicht im Bereich der neutralen Phasen an den Seitenflächen Verdickungen aufweist;

Figur 5 ein zweites Ausführungsbeispiel eines Piezoaktors, bei dem eine äußere Deckschicht im Bereich der neutralen Phasen an den gegenüberliegenden Ecken Verdickungen aufweist;

Figur 6 ein drittes Ausführungsbeispiel eines Piezoaktors, bei dem die Elektroden im Bereich der neutralen Phasen Verdickungen aufweist und

Figur 7 ein viertes Ausführungsbeispiel eines Piezoaktors, bei jeweils eine Isolationsschicht zwischen den lagen angebracht ist, die im Bereich der neutralen Phasen an den Seitenflächen Verdickungen aufweist.

Beschreibung der Ausführungsbeispiele

In Figur 1 ist ein Piezoaktor 1 gezeigt, der in an sich bekannter Weise aus Piezofolien 2 eines Quarzmaterials mit einer geeigneten Kristallstruktur aufgebaut ist, so dass unter Ausnutzung des sogenannten Piezoeffekts bei Anlage einer äußeren elektrischen Spannung an Elektroden 3 und 4 über Kontaktflächen 5 und 6 eine mechanische Reaktion des Piezoaktors 1 erfolgt.

Aus Figur 2 ist ein Bereich des Piezoaktors 1 vergrößert dargestellt, der die Elektroden 3 und 4 zeigt, wobei hier auch die Kontaktierung der Elektroden 4 mit der Kontaktfläche 6 zu erkennen ist. Da die Elektroden 3 aufgrund der anderen Polarität einen Abstand zu dieser Kontaktfläche 6 einhalten müssen sind hier neutrale Phasen gebildet, die anhand der neutralen Phase 7 beispielhaft dargestellt sind. Aufgrund des somit räumlich unterschiedlichen Auftretens des Piezoeffekts entstehen mechanische Spannungen in der neutralen Phase 7, die zu einer Materialbeeinträchtigung führen, die mit der gewellten Linie 8 schematisch angedeutet ist.

Nach Figur 3 ist der Bereich aus der Figur 2 mit einer angelegten elektrischen Spannung gezeigt, wobei die dadurch hervorgerufene mechanische Reaktion des Piezoaktors mit Pfeilen 9 und 10 verdeutlicht ist. Hierbei ist erkennbar, dass im Bereich der neutralen Phase 7 eine geringere Ausdehnung in Richtung der Pfeile 9 und daher eine Kraftwirkung in Richtung des Pfeiles 10 bewirkt wird, die zu Rissbildung im Bereich 8 der neutralen Phase führt.

Ein erstes Ausführungsbeispiel der Erfindung wird anhand Figur 4 erläutert, bei dem eine äußere Deckschicht 11 auf dem Mehrschichtaufbau angeordnet ist, die im Bereich der neutralen Phase 7 mit einer Verdickung 12 versehen ist,

welche im äußeren Maximum eine Größenordnung von 2 bis 8 µm erreichen kann. Mit dieser Verdickung 12 kann beim Einspannen des Piezoaktors 1 eine Vorspannung im Bereich der neutralen Phasen 7 aufgebracht werden, die die Rissbildung im Bereich 8 der Elektroden 3 und 4 verhindert (siehe Fig. 3).

Aus Figur 5 ist eine zweites Ausführungsbeispiel zu entnehmen, das eine äußerer Deckschicht 11 mit Verdickungen 13 zeigt, die an gegenüberliegenden Ecken des Piezoaktors 1 angeordnet sind. Die neutralen Phasen 7 sind hier ebenfalls an den Ecken ausgebildet, da bei diesem Ausführungsbeispiel die Kontaktierung der Elektroden 3 und 4 über eine an den Ecken angebrachte Kontaktfläche 14 und eine nicht sichtbare diagonal gegenüberliegenden Kontaktfläche erfolgt.

Beim Ausführungsbeispiel nach Figur 6 wird eine Verdikkung im Bereich der neutralen Phase 7 durch eine lokale Verdickung der Elektroden 3 und 4 ausschließlich im Bereich der neutralen Phasen 7 bewirkt.

Ein weiteres Ausführungsbeispiel nach Figur 7 zeigt einen Piezoaktor 1, bei dem im Bereich der neutralen Phase 7 eine hier extra verdickte Isolationsschicht 15 zwischen den Piezolagen 2 eingebracht ist, um auch hier beim Einspannen des Piezoaktors 1 eine Vorspannung aufzubringen, die eine Rissbildung zu verhindert.

Patentansprüche

1) Piezoaktor, mit

- einem Mehrschichtaufbau von Piezolagen (2) und dazwischen angeordneten Elektroden (3,4),
- einer wechselseitigen seitlichen Kontaktierung (5,6) der Elektroden (3,4), wobei im Bereich zwischen zwei Piezolagen, der eine an der jeweils gegenüberliegenden Seite kontaktierte Elektrode (3,4) aufweist eine neutrale Phase (7) ohne Elektrodenschicht vorhanden ist und mit
- einer Formgebung des Mehrschichtaufbaus über die eine erhöhte mechanische Spannung, bei einer Einspannung des Piezoaktors (1) senkrecht zum Lagenaufbau, im Bereich der neutralen Phasen (7) aufbringbar ist.

2) Piezoaktor nach Anspruch 1, **dadurch gekennzeichnet, dass**

- mindestens eine äußere Deckschicht (11) des Mehrschichtaufbaus an der äußeren Endfläche so gestaltet

ist, dass diese im Bereich der neutralen Phasen (7) eine Verdickung (12;13) aufweist.

3) Piezoaktor nach Anspruch 2, **dadurch gekennzeichnet, dass**

- die Verdickung (12) an gegenüberliegenden Seiten der Deckschicht (11), entsprechend der Anordnung der neutralen Phasen (7), angeordnet ist.

4) Piezoaktor nach Anspruch 2, **dadurch gekennzeichnet, dass**

- die Verdickung (13) an diagonal gegenüberliegenden Ekken der Deckschicht (11) entsprechend der Anordnung der neutralen Phasen (7) angeordnet ist.

5) Piezoaktor nach einem der Ansprüche 2 bis 4, **dadurch gekennzeichnet, dass**

- die Verdickung durch Schleifen der Deckschicht gebildet ist.

6) Piezoaktor nach Anspruch 1, **dadurch gekennzeichnet, dass**

- zwischen (einigen oder allen ?) Lagen des Mehrschichtaufbaus eine Isolationsschicht (15) angeordnet ist, die im Bereich der neutralen Phasen (7) jeweils eine Verdickung aufweist.

7) Piezoaktor nach Anspruch 1, **dadurch gekennzeichnet, dass**

- die Elektroden (3,4) des Mehrschichtaufbaus im Bereich der neutralen Phase (7) jeweils eine Verdickung aufweisen.

8) Piezoaktor nach einem der Ansprüche 2 bis 7, **dadurch gekennzeichnet, dass**

- einige oder alle Merkmale dieser Ansprüche miteinander kombiniert sind.

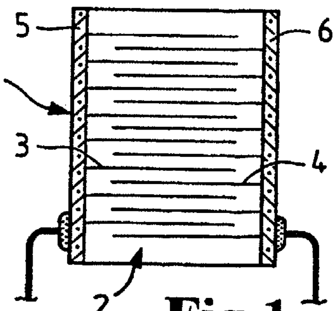

Fig.1

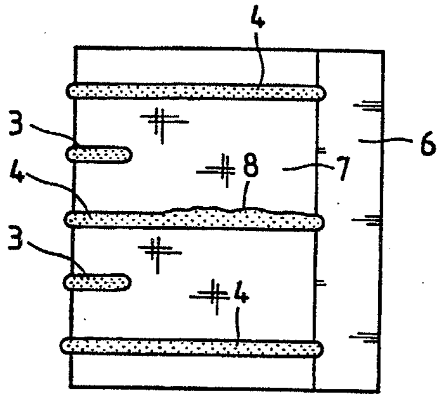

Fig.2

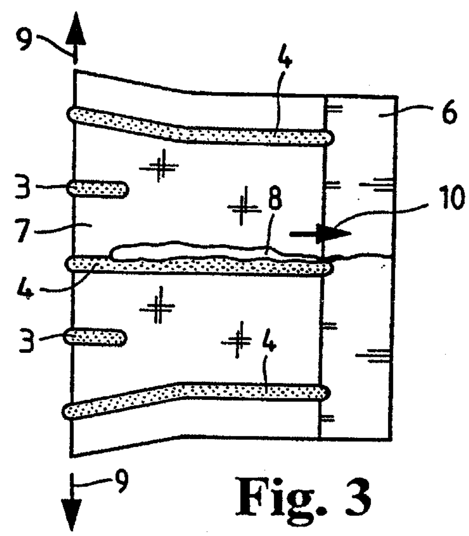

Fig. 3

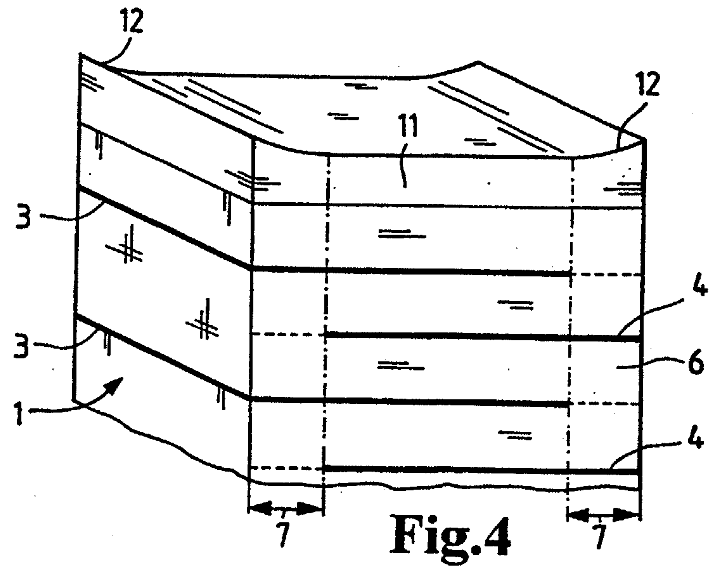

Fig.4

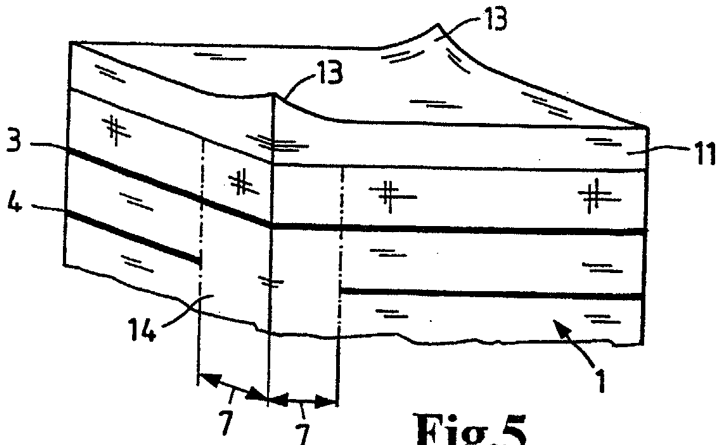

Fig.5

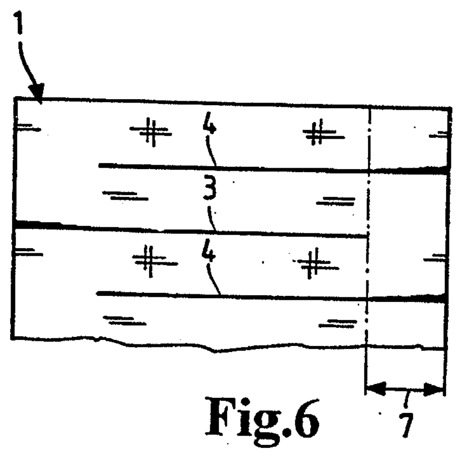

Fig.6

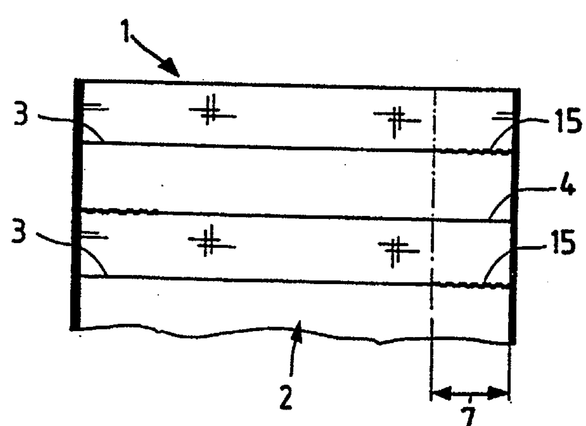

Fig.7

..(TERNATIONAL SEARCH REPO.

Inte ional Application No
PCT/DE 00/01929

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L41/083

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 266 862 A (OHYA KAZUMASA) 30 November 1993 (1993-11-30) column 2, line 3-21; figure 3	1
A	EP 0 479 328 A (NIPPON ELECTRIC CO) 8 April 1992 (1992-04-08) abstract; figure 8	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2000	07/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Pelsers, L

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/DE 00/01929

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5266862	A	30-11-1993	JP	4159785 A	02-06-1992
EP 0479328	A	08-04-1992	DE	69109990 D	29-06-1995
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			JP	4214686 A	05-08-1992
			US	5237239 A	17-08-1993

INTERNATIONALER RECHERCHENBERICHT

Internationales Aktenzeichen
PCT/DE 00/01929

A. KLASSIFIZIERUNG DES ANMELDUNGSGEGENSTANDES
IPK 7 H01L41/083

Nach der Internationalen Patentklassifikation (IPK) oder nach der nationalen Klassifikation und der IPK

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IPK 7 H01L

Recherchierte aber nicht zum Mindestprüfstoff gehörende Veröffentlichungen, soweit diese unter die recherchierten Gebiete fallen

Während der internationalen Recherche konsultierte elektronische Datenbank (Name der Datenbank und evtl. verwendete Suchbegriffe)

EPO-Internal, PAJ

C. ALS WESENTLICH ANGESEHENE UNTERLAGEN

Kategorie°	Bezeichnung der Veröffentlichung, soweit erforderlich unter Angabe der in Betracht kommenden Teile	Betr. Anspruch Nr.
A	US 5 266 862 A (OHYA KAZUMASA) 30. November 1993 (1993-11-30) Spalte 2, Zeile 3-21; Abbildung 3	1
A	EP 0 479 328 A (NIPPON ELECTRIC CO) 8. April 1992 (1992-04-08) Zusammenfassung; Abbildung 8	1

☐ Weitere Veröffentlichungen sind der Fortsetzung von Feld C zu entnehmen

☒ Siehe Anhang Patentfamilie

° Besondere Kategorien von angegebenen Veröffentlichungen :

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Datum des Abschlusses der internationalen Recherche	Absendedatum des internationalen Recherchenberichts
30. Oktober 2000	07/11/2000

Name und Postanschrift der Internationalen Recherchenbehörde	Bevollmächtigter Bediensteter
Europäisches Patentamt, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Pelsers, L

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INTERNATIONALER RECHERCHENBERICHT

Angaben zu Veröffentlichungen, die zur selben Patentfamilie gehören

Internationales Aktenzeichen
PCT/DE 00/01929

Im Recherchenbericht angeführtes Patentdokument		Datum der Veröffentlichung	Mitglied(er) der Patentfamilie			Datum der Veröffentlichung
US 5266862	A	30-11-1993	JP	4159785	A	02-06-1992
EP 0479328	A	08-04-1992	DE	69109990	D	29-06-1995
			DE	69109990	T	12-10-1995
			JP	4214686	A	05-08-1992
			US	5237239	A	17-08-1993